

Muon anomalous magnetic moment in models with singlet fermions

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Abstract

It is shown that a minimal extension of the standard model with leptons that transform as singlets under the $SU(2)$ symmetry of weak interactions can explain the recently reported deviation in the measured value of the anomalous magnetic moment of the muon from that expected in the standard model.

Recently the Muon ($g-2$) Collaboration [1] has reported a measurement of the anomalous magnetic moment of the positively charged muon,

$$a_{\mu}^{exp} = 11659202(14)(6) \pm 165 \cdot 10^{-11}. \quad (1)$$

The value expected in the standard model is

$$a_{\mu}^{SM} = 11659159.6(6.7) \cdot 10^{-11} \quad (2)$$

There seems to emerged a discrepancy of 2.6σ deviation between theory and the world averaged experimental value

$$a_{\mu}^{exp} - a_{\mu}^{SM} = 426 \pm 165 \cdot 10^{-11}. \quad (3)$$

Moreover, at 90% confidence level, the measurement indicates a relatively large effect due to "new physics" beyond the standard model. Since the value tends to lie in the "positive" rather than in the "negative" direction, it would appear that the discrepancy can only accommodate a very selective type of new physics. To the contrary, the discrepancy allows for several possible scenarios [2] to be entertained; supersymmetry [3], scalar leptoquarks [4], substructure[5], muon substructure [6], new gauge bosons[7], exotic fermions [8] and models for neutrino masses[9]. Here, a minimal extension of the standard model is proposed which contains fermions transform as singlets under the $SU(2)$ of electroweak interactions.

One way to motivate the extension of the standard model with singlet fermions is the generalized see-saw mechanism [10], widely discussed in the context of neutrino masses. The generalized see-saw mechanism explains in similar terms the smallness of the masses of the fermions belonging to at least the first two generations. Here, to keep matters simple, we propose to extend the second family with singlet charged leptons M_L and M_R that are vectorlike , i.e., they transform as

$$M_L \sim (1, 1, -2), \quad M_R \sim (1, 1, -2), \quad (4)$$

under the standard model gauge group $SU(3) \times SU(2) \times U(1)$. The model still contains the conventional quarks and leptons and a single doublet of Higgs and is free from triangle anomalies. The singlet fermions may have a bare mass term since no symmetry forbids it.

The coupling of the fermions to the muons are given by

$$L = Y_{\mu M}(\bar{\nu}_\mu \bar{\mu})_L i\sigma_2 \Phi^* M_R + m_{\mu M} \bar{M}_L \mu_R + (\text{H.C}), \quad (5)$$

where $Y_{\mu M}$ and $m_{\mu M}$ refer to Yukawa couplings. Without loss of generality we take $Y_{\mu M}$ equal to $m_{\mu M}$. After spontaneous symmetry breaking, there is left over the usual Higgs boson h^0 with coupling $Y_{\mu M}$ to the μ and M .

The contribution of the singlet heavy charged lepton M to a_μ is due to its couplings to the neutral Higgs boson and the muon as shown in Fig.1. This contribution is given by [11]

$$a_\mu = \frac{Y_{\mu M}^2 m_\mu^2}{8\pi^2} \int_0^1 \frac{x^2(1-x) + x^2 m_M/m_\mu}{x(x-1)m_\mu^2 + x m_M^2 + (1-x)m_h^2} dx. \quad (6)$$

Here a_μ is defined as the coefficient of the term

$$ie \frac{\sigma_{\mu\nu} q^\nu}{4m_\mu} \quad (7)$$

in the effective Lagrangian. There are additional contributions with standard model gauge boson exchange but they are known to be small. In evaluating a_μ , we take the Higgs boson to be light with mass $m_H = 100$ GeV, which is compatible with the present bounds from phenomenology. In Fig.2, a_μ is plotted as a function of m_M varying between 0.1 TeV and 5 TeV for three different values of $Y_{\mu M}$. At 90% confidence level a_μ lies between

$$21.5 \times 10^{-10} \leq a_\mu \leq 63.7 \times 10^{-10}. \quad (8)$$

As can be seen from Fig.2 these bounds select the value of $Y_{\mu M} = 0.1$ and the following bounds on the mass of the singly charged lepton

$$3 \text{ TeV} \geq m_M \geq 1 \text{ TeV}. \quad (9)$$

The present limits on the mass of singly charged heavy lepton are $m_M \sim 95$ GeV [12]. Thus, with $Y_{\mu M} \sim 0.1$ and m_M of order 1 TeV, the anomaly can easily be explained. It is to be noted that the addition of the singlet lepton leads to flavor changing processes such as $\mu \rightarrow e\gamma$. However, the predicted rate is model dependent and even if we make the conservative estimate of taking $Y_{\mu M} = Y_{eM}$, the rate is well below the bounds deduced from present experiments.

To conclude, if the reported anomaly [1] in the theoretical and experimental values of the muon anomalous magnetic moment of the muon withstands the test of time [13], then a simple viable explanation can be the standard model with an extended second generation of conventional fermions with weak $SU(2)$ singlets charged leptons. The singlet leptons required in the scheme lie within the reach of the near future upcoming accelerators.

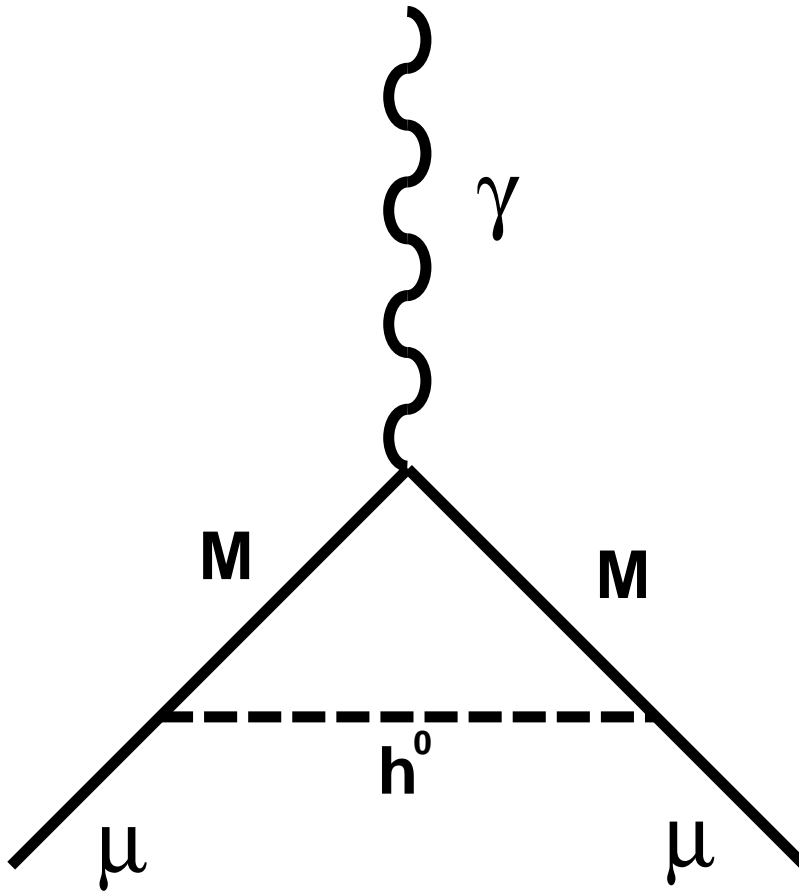


Figure 1: Singlet fermion contribution to muon anomalous magnetic moment.

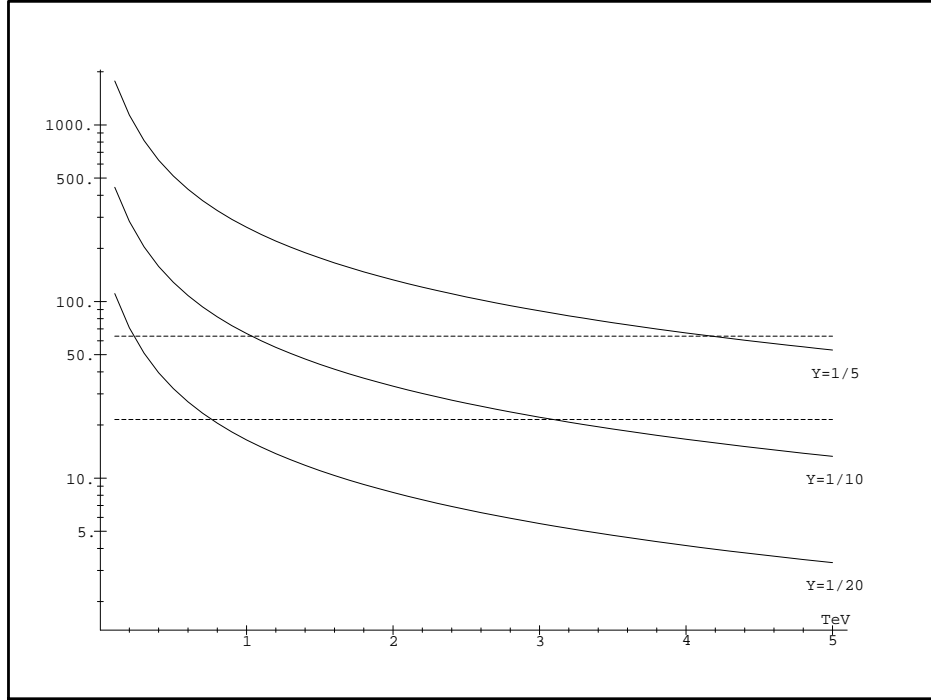


Figure 2: Muon magnetic moment $a_{\mu M}$ (multiplied by 10^{10}) as a function of $Y_{\mu M}$ and singlet lepton mass m_M .

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